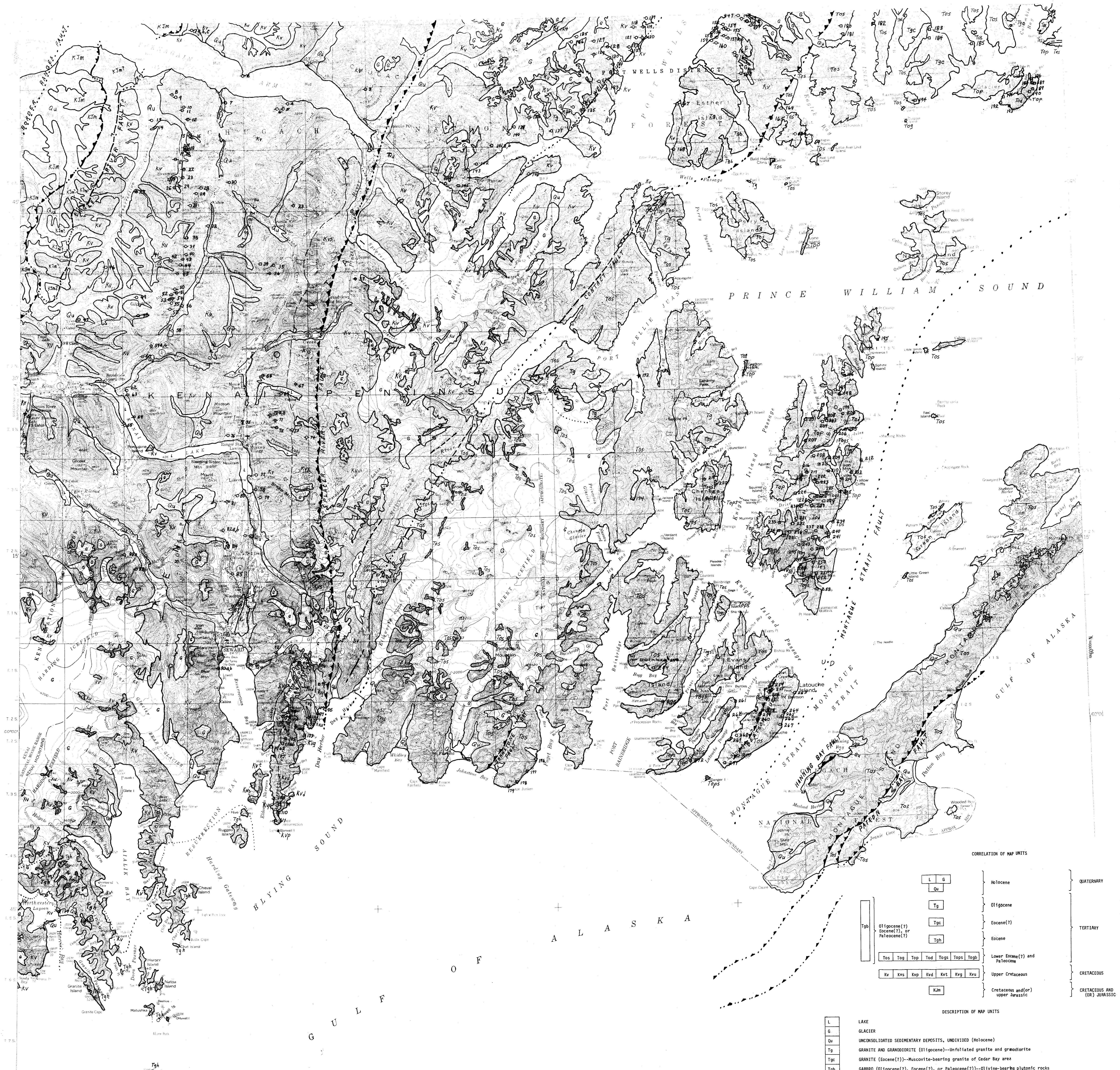
DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY

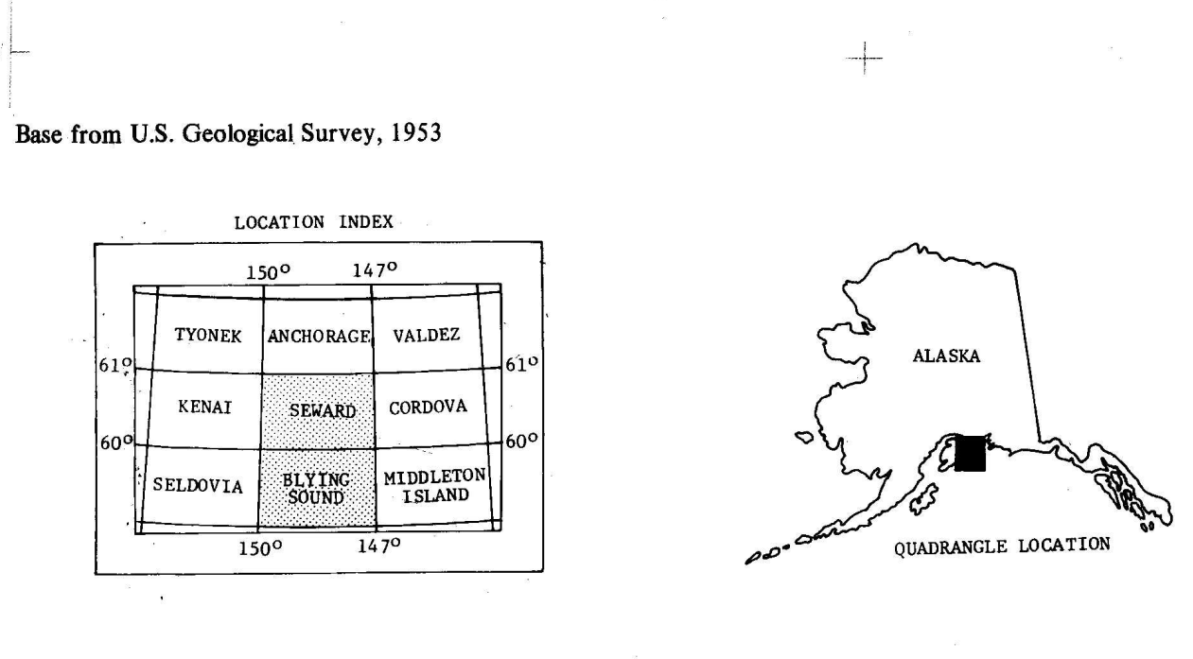
FOLIO OF THE SEWARD AND BLYING SOUND QUADRANGLES, ALASKA
MAP MF–880A
SHEET 1 OF 2
Tysdal-Mines, prospects, and occurrences



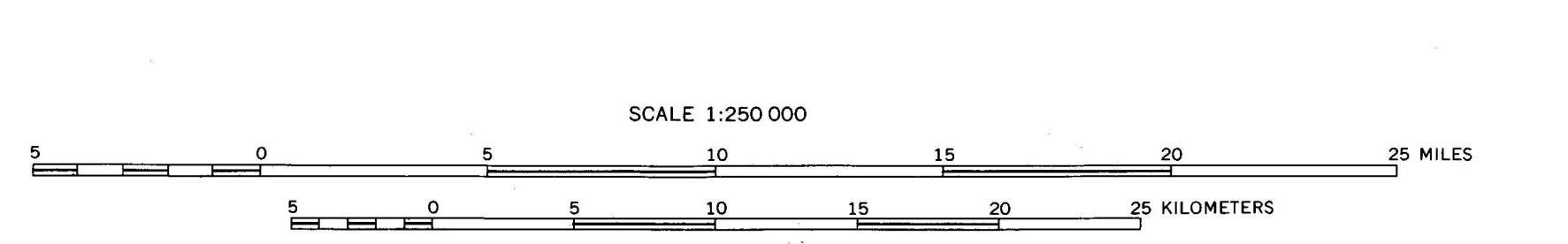
DESCRIPTION OF MAP UNITS

L	LAKE
G	GLACIER
Qu	UNCONSOLIDATED SEDIMENTARY DEPOSITS, UNDIVIDED (Holocene)
Tg	GRANITE AND GRANODIORITE (Oligocene)--Unfoliated granite and granodiorite
Tgc	GRANITE (Eocene(?))--Muscovite-bearing granite of Cedar Bay area
Tgb	GABBRO (Oligocene(?), Eocene(?), or Paleocene(?))--Olivine-bearing plutonic rocks
Tgh	GRANITE OF HARDING ICEFIELD REGION (Eocene)--Foliated granite
	ORCA GROUP (lower Eocene(?) and Paleocene)--Divided into:
Tos	SEDIMENTARY ROCKS, UNDIVIDED--Flysch of sandstone and siltstone
Tog	GREENSTONE, UNDIVIDED--Basaltic rocks not distinguished as to pillows, dikes, or tuffs
Top	PILLOW BASALT--Submarine extrusive basalt
Tod	SHEETED BASALT DIKES--Sequence composed almost wholly of dikes
Togs	GREENSTONE AND SEDIMENTARY ROCKS--Basalt sills and dikes intruding flysch
Tops	PILLOW BASALT AND SEDIMENTARY ROCKS--Interbedded pillow basalt and flysch
Togb	GABBRO--Small plutons and locally coarse-grained dikes
	VALDEZ GROUP (Upper Cretaceous)--Divided into:
Kv	SEDIMENTARY ROCKS, UNDIVIDED--Flysch of sandstone and siltstone, in part metamorphosed to slate and phyllite
Kvs	SCHIST--Sandstone, siltstone, and some tuffs metamorphosed to biotite grade of greenschist facies
Kvp	PILLOW BASALT--Submarine extrusive basalt
Kvd	SHEETED BASALT DIKES--Sequence composed almost wholly of dikes
Kvt	TUFF--Aquagene tuff interbedded with flysch
Kvg	GABBRO--Large pluton that intrudes sheeted dikes and flysch
Kvu	ULTRAMAFIC ROCKS--Small tabular bodies of serpentinized dunite
	McHUGH COMPLEX (Cretaceous and(or) Jurassic)
KJm	McHUGH COMPLEX--Weakly metamorphosed clastic and volcanic rocks; in large part is a melange

Base from U.S. Geological Survey, 1953



Compiled in 1977
Geology modified from
Tysdal and Case (in press)



CONTOUR INTERVAL 200 FEET
DATUM IS MEAN SEA LEVEL

MINES, PROSPECTS, AND OCCURRENCES MAP OF THE SEWARD AND BLYING SOUND QUADRANGLES, ALASKA

BY

RUSSELL G. TYSDAL

1978

MAP SYMBOLS

——––···· Contact--Dashed where approximately located; dotted where concealed

———···· High-angle fault--Dotted where concealed

▲▲··▲·· Thrust fault--Dotted where concealed. Sawteeth on upper plate

SYMBOLS FOR MAIN COMMODITIES

○	Gold or silver
◇	Chromium, cobalt, and(or) nickel
□	Copper
⌓	Antimony
⊕	Radioactive minerals (uranium and thorium)
▽	Nonmetal--Barite, haydite, limestone
⊙	Dot in symbol shows exact location

PRODUCTION DATA

(based on gold @ $130 per troy ounce, copper @ $.60 per pound)

○	Occurrence
-○	Prospect
-○-	Estimated production valued at less than $100,000
-○-	Estimated production valued between $100,000 and $1,000,000
-○-	Estimated production valued at more than $1,000,000

MINES, PROSPECTS, AND OCCURRENCES

Mines, prospects, and occurrences in the Seward and Blying Sound quadrangles are described briefly in this section. Information on the geologic setting, mineralogy, geochemistry, and origin is given for the different kinds of deposits. Detailed mine maps, correlated geochemical data, and other results of a detailed study of the Hope district (P. R. Mitchell, unpub. data, 1977) and description and genetic interpretations of the placer deposits (Tysdal, 1978) supplement this report.

The term "deposit" as used in this section refers to mines, prospects, and occurrences. Most of the mineral deposits shown on the map and table are known mines and prospects. Most of the occurrences are deposits found during investigations of the U.S. Geological Survey. They include deposits that may be worthy of study, as well as a few that are obviously minor.

INTRODUCTION

The Prince William Sound region may be considered as made up of two extensive and distinctive mineral belts defined by the preponderance of either gold or copper deposits (Capps and Johnson, 1915).[1] In the Seward and Blying Sound quadrangles, the division of the two belts is approximately along the Contact fault, which trends northeast across the quadrangles. The gold belt includes the Moose Pass-Hope district and the Port Wells district. The copper belt is exposed mainly on Latouche, Elrington, Bainbridge, Knight, Chenega, and Glacier Islands and the mainland area between Unakwik Inlet and Columbia Bay.

Rocks of the gold belt are chiefly slate and sandstone of the Cretaceous Valdez Group, whereas the copper belt contains abundant mafic igneous rocks, as well as slate and sandstone of the early Tertiary Orca Group. Some mafic igneous rocks also are within the gold belt, occurring along the Placer River fault which forms the eastern margin of the Moose Pass-Hope gold district. These older mafic rocks are most common on the Resurrection Peninsula near Seward, and the copper deposits are coincident with them. Mafic igneous rocks also exist within the schist north of the peninsula (Tysdal and Case, 1977; in press), and one copper lode (34) is known near the northern end of the schist unit. Conversely, gold deposits are present in the western part of the copper belt, chiefly in slate and sandstone. The copper deposits contain a significant amount of gold and silver, whereas the gold deposits contain a small amount of copper as well as silver (Johnson, 1918b; Moffit, 1954).

The metallic, nonmetallic, and energy resources of the quadrangles are described sequentially. Copper, gold, and silver have been produced in the study area and constitute the important commodities; accordingly, they are described early in the section on metal commodities. They are discussed more fully than the other metal commodities, which are described in alphabetical order. Locations of occurrences, prospects, and mines, as well as summary data for each individual deposit, are given in the accompanying map and table.

METAL COMMODITIES

Copper

The copper deposits of the Prince William Sound region are mainly stratabound, massive, and disseminated sulfides of volcanogenic origin (Wiltse, 1973; Winkler, 1976; Winkler and others, 1977), and a genetic relationship exists between the occurrence of volcanogenic mineralization and mafic igneous rocks. In this section, the mafic rocks are described briefly, followed by a discussion of the sulfide deposits of Knight Island where a close genetic and spatial relationship of the ore deposits and the mafic rocks is demonstrable. The copper-rich deposits of Latouche Island are then described in some detail, followed by a section that uses geologic and geophysical data to correlate the deposits of Knight and Latouche Islands. The final section describes some existing ideas on the origin of the copper deposits.

The mafic rocks of the copper belt are oceanic tholeiites deposited near the continental margin concurrently with deposition of flysch (Tysdal and others, 1977; Winkler, 1976; Winkler and others, 1977). On Knight Island the sequence of rocks can be viewed ideally as a mirror-image package that, from the margins toward the center of the island, consists of flysch; pillow basalts, with local areas of interlayered sedimentary rocks; sheeted basalt dikes; and small gabbro intrusive bodies. The sheeted dikes intrude sedimentary rocks at the north and south ends of the area of dikes (Tysdal and others, 1977; Tysdal and case, in press). Glacier Island, which is north of Knight Island, consists of flysch, pillow basalts with local areas of interlayered flysch, and sheeted basalt dikes. Bainbridge, Evans, and Elrington Islands, south of Knight Island, contain flysch, pillow basalts, large areas of pillow basalts and interlayered flysch, and basalt sills (Tysdal and Case, in press).

Knight Island

Copper was produced from chalcopyrite-bearing lenses in sheeted basalt dikes on the west side of Knight Island, but none of the mines produced more than a few thousand kilograms of copper. The Copper Bullion prospect (213) on the east side of Knight Island contains the largest and best known copper deposit of the island. It has been studied by several teams of geologists, most extensively by Stefansson and Moxham (1946) from whom the following summary was made. The deposits consist of sulfide-rich lenses that are surrounded by disseminated sulfides. The largest lens, which is 120 m long and 18 to 30 m in average thickness, is truncated by a fault on its north end. The lenses consist of massive pyrrhotite that contains veinlets and irregular patches of chalcopyrite and minor sphalerite. The lenses are within a steep, 120-m-wide shear zone that strikes northeast. Rocks near the deposit include pillow basalt, quartz diorite, and fine-grained altered greenstone. Stefansson and Moxham estimated that the largest lens contains about 1 billion kg (1,125,000 short tons) of indicated reserves that average 1.25 percent copper. Several million tons of 0.6 to 1.25 percent copper ore is present in the known ore bodies (Richter, 1965). Richter also reported that electromagnetic surveys by the U.S. Bureau of Mines indicated other, concealed, mineralized bodies.

Latouche Island

More than 99 percent of the copper produced in the Seward and Blying Sound quadrangles and the major production from the entire Prince William Sound region came from the copper deposits of Latouche Island, and the geologic setting of these deposits is described in some detail. The sulfide deposits of Horseshoe Bay south of the Beatson mine (256) do not contain significant amounts of copper ore, but they are described in some detail because knowledge of their genesis is an important exploration guide. The copper-rich Chenega (255), Blackbird (254), and Beatson (256) mines, originally under separate ownership, were operated by the Kennecott Copper Corporation from 1910 until 1930 when ore of commercial grade was depleted (Moffit and Fellows, 1950). These mines were the second largest contributor of copper in Alaska, producing about 90 million kg (about 200 million lbs) of copper and several tens of million grams (several million ounces) of byproduct silver.

The Beatson deposit (256), the largest and richest of the three ore bodies, was described most fully by Bateman (1924) from whom the following summary was made. The Beatson consisted chiefly of sulfides disseminated in gangue of sandstone and lesser flinty rock, "green schist," and slate. Chalcopyrite constituted about 50 percent of the sulfides, pyrite and pyrrhotite about 25 percent each. The ore body, localized chiefly in sandstone of the early Tertiary Orca Group, was lens-shaped and elongate north-south about parallel to the steep westward dip of bedding. It had a maximum width of about 120 m and a maximum length of about 300 m. The Beatson fault formed a sharp western limit to the lens, whereas the eastern boundary of the lens was gradational and marked by decreasing amounts of disseminated sulfides. The richest ore, shipped directly to the smelter, consisted of veinlets and blebs of chalcopyrite in the "green schist" immediately adjacent to the Beatson fault. Northward along this fault were the Blackbird (254) and the Chenega (255) ore bodies which displayed the same general characteristics as the Beatson deposit but were smaller.

The deposits of Horseshoe Bay (258, 259) were investigated for their copper content in the early part of the century. Pyrite is the principal sulfide mineral, constituting nearly 100 percent of the potential ore at several places. Other sulfide minerals include chalcopyrite, cubanite, sphalerite, and pyrrhotite. The Duchess deposit (258), summarized from Stejer's (1956) report, consists of a series of westward-dipping lenses of massive sulfides that range in width from a few centimeters to 18 m and in length from a few centimeters to 150 m. They were emplaced parallel to bedding in slate and sandstone of the early Tertiary Orca Group. The widespread disseminated sulfides mainly form halos around lenses of massive sulfides. Boundaries between massive and disseminated sulfides are sharp along footwalls and transitional over 7 to 10 cm along hanging walls. Boundaries between disseminated sulfides and country rock are transitional over 0.6 to 1 m on the footwall side and transitional over as much as 30 m on the hanging wall side. Stejer believed that the sulfides were deposited preferentially in the coarser grained "graywackish" rocks. The mineralized zone is relatively free of faults, and none of the massive sulfides is truncated or displaced. A prominent fault 20 to 30 m west of the portal to one massive sulfide lens may be a continuation of the Beatson fault as advocated by Moffit (1954).

The Duke and related claims (259) were less extensively explored but are geologically similar to the Duchess. Four massive sulfide lenses are present, ranging from 1.3 to 8 m in thickness with a maximum proved length of 45 m. The zone favorable for occurrence of sulfide lenses is at least 930 m long and is largely unexplored.

Several lines of evidence suggest that ore deposits of the northern part of Latouche Island are closely related in origin. There is a repeated zonation from west to east of: (a) Beatson fault, (b) lenses of massive pyrrhotite and (or) pyrite immediately adjacent to the fault, (c) greatest concentration of copper ore immediately adjacent to the fault, and (d) at the northern three mines (254, 255, 256), disseminated chalcopyrite decreases in concentration eastward. The pattern exists for at least the 5 km of fault along which the five mine workings are located.

Mineralization of Latouche Island is spatially associated with the Beatson fault which, in the Beatson mine (256), is marked by a zone of gouge, sheared and shattered rock, and cavey ground (Bateman, 1924). The fault dips about 60 degrees to the west, extends northward through the Chenega (255) and Blackbird (254) mine workings, southward through the Duchess mine (258), and, according to Moffit (in Bateman, 1924, p. 348; Moffit, 1954), may continue southward through the Seattle-Alaska mine (270). Bateman (1924) believed that the Beatson fault zone with its related shearing unquestionably was the chief cause of the localization of the Beatson, Chenega, and Blackbird ore bodies.

A massive body of pyrite and pyrrhotite lies immediately east of the Beatson fault in the Beatson mine in addition to the disseminated copper ore (Bateman, 1924). The body is more than 250 m long and ranges from 0.6 to 12 m in width. Southward at the Duchess (258) and Duke (259) properties, Stejer (1956) described several massive pyrite bodies, as much as 150 m long, lying east of the Beatson fault.

The richest chalcopyrite ore at the Beatson mine (256) was obtained immediately east of the Beatson fault (Bateman, 1924). At the Duchess Mine (258) chalcopyrite is most abundant in the shear zone on the hanging wall side (west side) of the solid sulfide lens (Johnson, 1918b). Disseminated chalcopyrite at the Beatson, Blackbird, and Chenega mines formed large lenses of minable copper ore, but disseminated chalcopyrite at the Duchess and Duke mines is meager.

The massive sulfides of pyrrhotite and (or) pyrite of the five mines along the northern part of the Beatson fault establish a spatial tie for mineralization. This relation leads to a hypothesis that Beatson-type deposits may be present southward along the Beatson fault. Geophysical methods of exploration might prove profitable in an attempt to detect concealed bodies of similar massive sulfides (that could have associated copper sulfides) farther south along the Beatson fault.

Correlation of rocks

Study of the folds in the sedimentary rocks interlayered with the mafic igneous rocks of Knight Island appears to define a complex anticline, plunging to the south with the axis along the approximate center line of Knight Island (Richter, 1965). Map patterns of the rock units on Knight, Latouche, Elrington, Evans, and Bainbridge Islands suggest that the entire package of rocks plunges to the south (Tysdal and Case, in press), and gravity maps (Case and others, 1966; Case and others, in press) show that a gravity anomaly of +50 mgal over the mafic rocks of Knight Island continues southward, decreasing in value, beneath the more southerly islands. Thus rocks of Knight Island represent the lowermost exposed rocks of all five islands, whereas the rocks of Latouche, Elrington, Evans, and Bainbridge Islands represent a stratigraphically and structurally higher sequence of rocks. In other words, the sequence of rocks in the southern four islands should be representative of rocks that have been eroded from Knight Island.

The Latouche ore deposits lie on the flank of this major sequence of igneous and sedimentary rocks and are structurally high in the sequence. The few known mafic rocks on Latouche Island consist of sills near the northeastern and southeastern extremities of the island and an altered olivine-bearing dike (Bateman's, 1924, p. 346, "lamprophyre dike") at the Beatson mine (256). Pillow basalt crops out on Danger Island, a small island south of Latouche Island.

To determine if a regional pattern exists in the distribution of sulfides, a tabulation was made of the most abundant sulfide mineral present, when recorded in the literature, at each of the prospects, mines, and occurrences on Glacier, Knight, Latouche, Elrington, and Bainbridge Islands. The data presented in the following two paragraphs show only the distribution of reported chief sulfide minerals and do not reflect the possibility of more than one age of mineralization or remobilization of ores. The data do show, however, that the most abundant sulfide mineral at a locality is preferentially concentrated in a particular geologic unit or environment, whether or not the mineral was remobilized. Thus, in general, pyrite is the chief sulfide mineral in pillow basalts and in some sheeted basalt dikes near pillow basalts; pyrrhotite is the chief sulfide in some basalt dikes near pillow basalts; and chalcopyrite is the chief sulfide mineral in sheeted basalt dikes and is distributed throughout the width of the zone of sheeted dikes. Chalcopyrite is commonly the chief sulfide mineral in sedimentary rocks.

For the mafic igneous rocks of Knight and Glacier Islands, pyrite is the chief sulfide reported at ten localities (186, 187, 202, 207, 211, 215, 216, 217, 218, 233), including six in pillow basalts, three in sheeted basalt dikes near pillows, and one locality not near the contact. Pyrrhotite is the chief sulfide reported at six localities (191, 205, 209, 213, 214, 223), four in sheeted basalt dikes near the contact with pillow basalts, one (209) in dikes distant from the contact, and one (213), the Copper Bullion prospect, in pillow basalts. Chalcopyrite was the chief sulfide reported at seven localities (192, 210, 226, 230, 238, 244, 246), all in sheeted basalt dikes.

For the rocks of Latouche, Elrington, and Bainbridge Islands and the sedimentary rocks of Knight Island, pyrrhotite was not reported as the chief sulfide at any locality. Pyrite was the chief sulfide reported at three localities (258, 259, 275), all in sedimentary rocks with locality 275 adjacent to pillow basalt. Chalcopyrite was the chief sulfide reported at eleven localities (251, 252, 254, 255, 256, 264, 266, 267, 269, 270, 273), all in sedimentary rocks with localities 251, 252, and 273 near basaltic intrusive rocks.

Chalcopyrite in the mafic igneous rocks of Knight and Glacier Islands preferentially occurs in the sheeted dikes. The largest concentration of it is at the Copper Bullion prospect (213), which may be in a zone of transition from sheeted dikes into pillow basalts. Chalcopyrite commonly was reported in the literature as the most abundant sulfide in sedimentary rocks, although lenses of massive pyrite and pyrrhotite are present.

Origin

All workers who have studied the ore deposits of the copper belt have concluded that the copper ores are genetically related to the mafic igneous rocks. Johnson (Capps and Johnson, 1915), in his early studies, attributed the sulfides to granitic magma but later concluded that mafic igneous magma was the source of the ore fluids (Johnson, 1918b, p. 202). Theories for the origin of the deposits in the map area generally have centered on Knight Island where ore deposits and mafic rocks are closely associated. A direct correlation of the Latouche deposits with a mafic magmatic source is not possible because the deposits are isolated in slate and sandstone. Nevertheless, the ore deposits at Latouche are part of a similar group of ore deposits that characterize the copper belt of Prince William Sound, and all of the investigators who have studied the Prince William Sound deposits concluded that the Latouche deposits must be related to the mafic igneous rocks.

All of the known massive sulfide deposits are reported to occur in shear zones. Johnson (1918b) believed that the shear zones in the mafic rocks probably formed during the succession of intrusions and extrusions that built up Knight Island, providing channels for mineralizing solutions. Richter (1965) concluded that deposition of the massive sulfides of Knight Island probably occurred more or less contemporaneously with metamorphism, shearing, and folding of the mafic rocks. Deposition of massive sulfides apparently was controlled by secondary structures that formed local areas of reduced pressure within the major shear zones during metamorphism (Richter, 1965, p. 15-16). Where relations are interpretable, Richter found massive sulfides of the shear zones (1) in areas of subtle changes in direction of schistosity, (2) in warped schist at the contact of large bodies of competent rock (competent rock is static), and (3) in strongly warped schist at the apices of small lenses or boudins of competent rock (competent rock has been rotated).

Wiltse (1973), on the other hand, favored a volcanogenic origin for the ores of Knight Island. His observations showed an asymmetrical distribution of zinc values within lensoid ore bodies, confinement of ore to subaqueous tuff units, depletion of metals adjacent to spatially related shear zones, and a lack of hydrothermal wallrock alteration. McGlasson (1976) also concluded that sulfide mineralization on Knight Island is premetamorphic in origin, indicated by (1) grains of chalcopyrite that have foliation oriented parallel to foliation of tuffaceous host rock; (2) grains of chalcopyrite that have been deformed between and around quartz grains in schist; (3) primary sedimentary structures preserved in sulfides (Wiltse, *in* McGlasson, 1976), and (4) snowball textures of quartz intermingled with chalcopyrite, with galena and sphalerite recrystallized in the pressure shadows (Wiltse, *in* McGlasson, 1976). Near the Ellamar mine in northeastern Prince William Sound (Cordova quadrangle) in a geologic setting similar to that at Latouche Island, G. R. Winkler (oral commun., 1976) observed sulfide minerals concentrated in the troughs of ripple marks. This observation also supports a synsedimentary origin for the sulfide mineral grains. Stefansson and Moxham (1946) cited the occurrence of several faults that juxtapose quartz diorite against mineralized rock at the Copper Bullion prospect (213) and concluded that mineralization preceded faulting.

The sedimentary structure-sulfide mineral relationships cited by McGlasson and Winkler are good arguments for mineralization during deposition of sediments. Arguments 1, 2, and 4 cited by McGlasson are similar to the arguments of Richter (1965) who reached the opposite conclusion. These three arguments are not definitive because the mineralizing fluids could have been remobilized, thus supporting McGlasson's viewpoint, or they could have been primary fluids that migrated along a channelway (the shear zone), were deposited, then subsequently resheared, thus supporting Richter's viewpoint.

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Some of the mafic igneous rocks were emplaced during or after deformation of the sedimentary rocks and after mineralization. Mafic rocks intrude and crosscut nearly vertical sedimentary rocks on Knight Island (Johnson, 1918b) and small gabbro bodies intrude both dikes and sedimentary rocks. Sills intrude vertical sedimentary beds on the islands south of Knight Island. Dikes intrude ore bodies at several places: (1) at the Copper Bullion prospect (213), mapping by Stefansson and Moxham (1947) shows dikes that cut massive and disseminated sulfides; (2) at the Jonesy mine (222) a narrow mafic dike intruded one of the larger shear zones, but itself is not sheared (Johnson, 1918b; Richter, 1965); (3) at the Knights Island Alaska Copper Co. mine (225) several mafic dikes 2 to 30 m thick and irregular masses of mafic rock cut and intruded the mineralized shear zone (Johnson, 1918b; Richter, 1965); and (4) at the Beatson mine (256) on Latouche Island the ore body is intruded by an unshattered, altered, olivine-bearing "lamprophyre" dike (Bateman, 1924). It is apparent that deposition of sediments, intrusion of mafic rocks, mineralization, deformation, and perhaps metamorphism were processes ongoing all at the same time, creating complex relationships.

Gold

Lode gold deposits are present in the Port Wells district and in the Moose Pass-Hope district. Gold production from the Seward quadrangle is known to be more than 153,000 troy ounces; about 46,000 troy ounces are from lodes, the remainder from placers. The placer deposits are described in a companion report (Tysdal, 1978). Gold also occurs in the copper ore of Prince William Sound, ranging from a trace to as much as 0.02 troy ounces per ton (Stejer, 1956; Johnson, 1918b).

Port Wells district

Gold lodes of the Port Wells district are in quartz or quartz-calcite veins that commonly range in width from a few centimeters to 1 or 2 m and extend a few tens of hundreds of meters in traceable length. Some veins are wider, the vein at the Granite mine (120) having a maximum width of about 5 m. The veins pinch and swell, and form irregular bunches, stringers, and tiny veinlets between breccia fragments. The quartz veins occupy fault and shear zones. Rocks between the walls of the shear zones were brecciated, subsequently cemented by mineralized quartz, and underwent at least local minor post-mineralization movement that is indicated by gouge along the vein walls and by cross-fracturing (Johnson, 1914a). The breccia fragments are of the same lithology as the country rock. In the Granite mine (120), where a shear zone cuts both sandstone and granite, the breccia is of the same lithology as the immediately adjacent country rock.

The mines and prospects in the western part of the Port Wells district (west of the body of water named Port Wells) all occur west of the Port Wells fault; however, this biased distribution pattern may be more apparent than real because there is little land east of the fault, particularly in the area of greatest mineralization. The Port Wells fault is a nearly vertical fracture that trends about N. 30° E., marked by a zone of shearing and brecciation several hundred meters wide. It is believed to have experienced both strike-slip (right lateral?) and dip-slip movement with the west side up. A large part of the movement probably preceded the regionally widespread granitic intrusions. Most of the mineralized faults, shears, veins, seams, and stringers in the western part of the district are oriented approximately 30° to the Port Wells fault and dip 75° to 85° W., on the basis of a study of structural orientations recorded by Johnson (1914a; unpub. data, 1913) at the various mines of the district.

The mineralized faults and shear zones cut slate and sandstone of the Cretaceous Valdez Group and granite and associated felsic dikes that intruded the Valdez. The granite is probably Oligocene in age, on the basis of potassium-argon dates of 34.4 to 36.6 million years (Lanphere, 1966) obtained from granitic plutons in the Prince William Sound area.

The gold lodes of the Port Wells district were interpreted by Johnson (1914a, 1915) as products of igneous activity. He observed hydrothermal alteration of country rock adjacent to the mineralized veins, sulfide-bearing pegmatites on Esther Island, and aplite dikes with quartz centers that contained sulfides, but he did not know if the mineralization was primary. Small granite bodies, some exposed only in mine workings, are near Hobo Creek in the area that includes the two largest gold producers of the district, the Granite (120) and Herman and Eaton (129) mines. Felsic dikes are much more common in this area of the western part of the district. Stibnite is known only from this area (localities 120 and 121), and sphalerite and galena are more abundant than in other gold lodes. Thus a spatial relation exists between granite and mineralization, and it seems likely that the Hobo Creek area and much of the rest of the western part of the district constitute the roof rocks of one or several granite bodies. The structural relations described require that mineralization postdates emplacement of the granite. The mineralizing solutions must have percolated along fractures and migrated from sources deeper than the exposed granite bodies, and it is not known if the mineralizing fluids were derived from a granite melt or if they were derived from country rock by some metamorphic differentiation process.

The eastern part of the Port Wells gold district was not as productive as the western part. Only two localities ('67, 168) are spatially associated with granite, and no granite was reported from any of the other mines or prospects. However, scheelite is exceptionally common in pan concentrate stream-sediment samples north of the Esther granite body to beyond the boundary of the Seward quadrangle (R. B. Tripp, oral commun., 1977). The presence of scheelite suggests that granite or felsic dikes from a granite body may underlie the eastern part of the Port Wells district. The contact metamorphic zone of the Esther granite body is several kilometers wide, more so to the north than to the east and northeast, suggesting that the body slopes to the north beneath slate and sandstone of the Valdez Group.

Gold of the Port Wells district is mainly free (Johnson, 1914a), but it also occurs in sulfide minerals (Stewart, 1931). The telluride mineral nagyagite was reported in the part of the Port Wells district that lies in the Anchorage quadrangle (Mines Handbook, 1927, p. 158), and it is possible that telluride mineralization may also exist in the Seward part of the district. Most of the gold lodes contain pyrite, chalcopyrite, arsenopyrite, and pyrrhotite, with the last three minerals being less abundant than pyrite. Sphalerite and galena also are found throughout the district in the Seward quadrangle. Silver was an important economic metal throughout the district (Johnson, 1914a, p. 217) but was reported at only two localities (121, 155), probably because it is amalgamated with gold.

Moose Pass-Hope district

Gold deposits of the central to northern part of the Moose Pass-Hope district were studied most recently by Tuck (1933) from whom much of the following data were taken. For those deposits in the southern part of the district, Martin, Johnson, and Grant (1915) is the main summary. Several mines and prospects in the Hope area, chiefly in the Palmer Creek drainage, were studied by P. R. Mitchell (unpub. data, 1977).

The gold lodes occur in quartz and quartz-calcite veins and in felsic dikes, both of which intrude slate and sandstone of the Cretaceous Valdez Group. The quartz veins range in width from a few centimeters to about 2 m, with an average width of 15 to 20 cm, and are traceable along strike for only a few tens of meters. The felsic dikes are commonly about 1 to 2 m thick and strike north about parallel to bedding of the country rock, except in the Bear Creek area where diverse trends are exhibited. Tuck (1933, p. 490-491) stated that one dike is traceable northward for as much as 17 km from the Gilpatrick property (54) to Frenchy Creek (31), passing through most of the mines and prospects in between. East of Palmer Creek, he showed another dike that is about 10 km long, but this intrusive body is known to be composed of several felsic dikes that locally have an en echelon arrangement. The individual dikes are not traceable continuously along the 10 km. Thus it may be more accurate to consider the igneous rocks as several intrusions in long, narrow zones. The age of the dikes is not known, but samples have been submitted for radiometric dating.

The dikes, most of which are nearly vertical, intruded shear and fault zones after regional deformation. They were later fractured and recemented by mineralized quartz concomitant with the deposition of mineralized quartz in the brecciated and sheared fault zones. Tuck (1933) reported that the larger and more richly mineralized veins commonly strike east, about normal to the strike of bedding of the country rock. Most of the veins underwent shearing and fracturing after mineralization.

The gold lodes of the Moose Pass-Hope district were interpreted as products of magmatic activity by Tuck (1933). Most of the mineralization occurs in the felsic dikes or in quartz veins near the dikes. Tuck believed that the ore-bearing solutions migrated upward through channels close to those through which the dike magma itself entered and that a magmatic reservoir underlay the area. No granite crops out in the district.

North of Turnagain Arm on Crow Creek, about 12 km north of Girdwood and in the Anchorage quadrangle, several small, coarse-grained quartz diorite plugs and pipes and abundant felsic dikes were mapped by Park (1933). Park thought that all these igneous rocks had a common origin and were closely related to mineralization. His map shows dikes to be abundant near the intrusions. He stated, as did Tuck (1933), that mineralization of the dikes does not fit a simple pattern--it is erratic. The mere presence of a dike does not indicate sulfide-mineral deposition.

A metamorphic zonation is evident in the eastern part of the Moose Pass-Hope district, and mineralization may be related to it. West from the Placer River fault, metamorphosed rocks of the Valdez Group grade from schist to phyllite to nonphyllitic slate and sandstone that, at least in the area bordered by Mills, Silvertip, Bench, and Johnson Creeks, contain abundant quartz veins; to slate and sandstone that does not contain abundant quartz veins. A large part of this area is drained by Mills Creek, which was one of the richest gold-placer streams in the district. Few gold prospects exist in the area, but abundant gold must have been present in the rocks (Tysdal, 1978). The quartz veins exploited west of Moose Pass and near the south end of Kenai Lake also are in slate and sandstone west of the phyllitic rocks. The eastern part of the Moose Pass-Hope district would be a good place to undertake geochemical sampling of rocks to evaluate the concept of gold concentration by metamorphic differentiation processes.

Arsenopyrite is the chief metallic mineral of the gold lodes, and it generally is associated with small amounts of galena, sphalerite, pyrite, chalcopyrite, and, rarely, pyrrhotite (Tuck, 1933; Martin and others, 1915). Silver was detected in assays of most of the veins, and minute amounts of tellurium were detected in quartz veins in the Hope area (P. R. Mitchell, unpub. data, 1977). Molybdenite was purported at several localities (Tuck, 1933, p. 491), but none was observed by Tuck or other workers.

Silver

Silver was recovered as a byproduct metal from both gold and copper mines, but no mines in the quadrangles were worked mainly for silver. The Kennecott operations at the Latouche copper mines (254, 255, 156) yielded several million troy ounces of byproduct silver, a total far in excess of that recovered from all of the gold mines combined. In 1916, 1917, and 1918, for example, silver recovered from Latouche ranged from about 1.7 to 6 troy ounces per ton of ore milled, which is about 55 to 200 parts per million (ppm) silver per ton or about 0.0006 to 0.002 percent silver per ton (calculated from data in Mines Handbook, 1920, p. 154).

Silver prospects in the map area were recorded only on Bear Creek near Hope. The Coon and Plowman prospect (9) was staked originally as a silver lode (Tuck, 1933, p. 507), and Martin, Johnson, and Grant (1915, p. 179) stated that "several other prospects reported valuable for their silver content" were located along Bear Creek. Only trace amounts of silver were detected in rocks of this drainage during our study. Native silver has been recovered from placer operations on Bear Creek, however, as well as on Palmer and Crow Creeks (Moffit, 1905, 1906). Martin, Johnson, and Grant (1915, p. 179) stated that most gold lodes of the Moose Pass-Hope district carry some silver, and our analyses in the Hope district show that a high percentage of the gold-bearing veins contain silver, although some silver-bearing veins and felsic dikes lack gold.

No silver minerals were identified. Silver is amalgated with gold in quartz vein deposits, but its association in the copper lodes is unknown.

Other metals

Metals described in this section were detected in anomalous amounts in some of the geochemical samples or, with few exceptions, are minor constituents of some of the mineral deposits. In general, this group of metals is regarded as having scant economic significance in the quadrangles, although some may be potential byproducts or constitute undiscovered economic deposits.

Antimony

Antimony is confined mainly to two areas of the Seward quadrangle, near Kenai Lake and in the Port Wells district. In addition, 200 ppm antimony was detected in a basalt with remnants of pillow structure (221) from Chenega Island. Grant and Higgins (1910a, p. 178) described a prospect (63) north of Kenai Lake that contains stringers and disseminated particles of stibnite in a sheared felsic dike. The deposit contains needles of stibnite in a small quartz vein that fills a fracture in the dike, but it apparently lacks gold and silver. More recently another antimony prospect (64) was staked about 3 km south of locality 63 (U.S. Bureau of Mines, 1973a, and KARDEX, 1976a). South of Kenai Lake, stibnite occurs in quartz veins at the Primrose mine (81) (Jasper, 1967, p. 3). Brooks (1916, p. 60) stated that a stibnite lode has been reported on Bear Creek near Hope, but neither Tuck's (1933) studies nor ours revealed antimony in this drainage. In the Port Wells district, stibnite associated with quartz veins occurs at the Sweepstake (125) and Granite (120) mines (Johnson, 1914a, 1915; Brooks, 1916).

Arsenic

Arsenic is a constituent of many of the gold lodes and reflects arsenopyrite, a common accessory mineral in the vein deposits. Several samples from gold mines in the Moose Pass-Hope district contained 5,000 ppm or more arsenic. The abundance of high arsenic values from this area no doubt reflects a greater sampling density as gold mines in other parts of the Seward quadrangle also contain abundant arsenic. No arsenic was detected in any of our samples from copper prospects or from mafic igneous rocks, but arsenopyrite is a minor mineral in some copper lodes.

Bismuth

Bismuth is rare; it was detected in minor amounts at only two localities. A value of 20 ppm was obtained from a quartz vein in the Hope area, and a value of 100 ppm was yielded by an iron-stained alteration zone at the margin of granite in the Harding Icefield area. The granite sample came from immediately west of the western margin of the Blying Sound quadrangle, near the south shore of Northwestern Lagoon (lat 59°45'22" W., long 150°01'50" N.).

Cadmium

Cadmium, a chemical associate of zinc, was detected in only four samples (from localities 12 and 20), all of which yielded anomalous amounts of zinc. Cadmium values ranged from 100 to 300 ppm.

Chromium

Chromium in amounts of 1,000 ppm or greater was detected in a few gabbroic rocks, but it is present chiefly in serpentinized dunite. A value of 1,000 ppm was obtained for sheared greenstone (219) of Chenega Island and from gabbro (104) on the Resurrection Peninsula. All other anomalous values, ranging from 1,000 to more than 5,000 ppm, were from small bodies of serpentinized dunite (101, 103) associated with the pillow basalt, sheeted dike, and gabbro complex of the Resurrection Peninsula (Tysdal and others, 1977). Background values for pillow basalts, sheeted dikes, gabbro, and mafic tuffs throughout the Seward and Blying Sound quadrangles commonly range between 10 and 200 ppm chromium with a few values in the 300 to 500 ppm range.

Cobalt

No cobalt minerals were observed. Anomalous cobalt values were detected on a small serpentine pod (a few hundred meters west of locality 96) (700 ppm); on serpentinized dunite at locality 97 (200 ppm); and, at locality 68, 300 ppm on sheared rock of the Placer River fault. Background values for serpentinized dunite of the Resurrection Peninsula range from 70 to 200 ppm cobalt. Background values for pillow basalts, sheeted dikes, gabbros, and mafic tuffs throughout the map area ranged between 5 and 70 ppm.

Lead

Lead is the chief commodity at only two prospects (1a, 127) where galena is the only metallic mineral reported in a quartz vein. Galena is a minor accessory mineral in many of the gold lodes. Lead in excess of 1,000 ppm was detected from several mines in the Hope district (P. R. Mitchell, unpub. data, 1977).

Manganese

The highest manganese value, greater than 5,000 ppm, was obtained from siltstone cut by a small, north-trending shear zone on the ridge between Palmer and Resurrection Creeks (lat 60°47'18" N., long 149°35'09" W.). Several channel samples from the Hirshey and Carlson mine (22), a gold lode, yielded 3,000 to 5,000 ppm manganese. These high values correspond to low values of iron from the same samples; conversely, high values for iron correspond to manganese values of 700 to 1,500 ppm, suggesting that manganese and iron substitute for each other at these localities.

Mercury

Many rocks from the quartz lode mines in the Hope area were analyzed for mercury, which was detected in nearly every sample. Values generally were less than 1 ppm, but a few rocks gave values in the range of 1 to 3 ppm, and three samples yielded values of 10 ppm (P. R. Mitchell, unpub. data, 1977). An increased mercury content corresponded to an increased value of gold obtained from the same sample. Analyses of free gold panned from the dump of the Nearhouse and Smith mine (12) shows mercury to be chemically combined with gold (R. B. Tripp, oral commun., 1976). Minute grains of cinnabar were reported in pan concentrate stream-sediment samples from the mouth of Bertha Creek and from a tributary of Cooper Creek (Jasper, 1967, p. 35, 45). However, no cinnabar was observed in the Seward or Blying Sound quadrangles in any of the several hundred pan concentrate stream-sediment samples analyzed by the U.S. Geological Survey. A similar appearing reddish mineral, minium (Pb_3O_4), which could be confused with cinnabar, was observed in several samples and confirmed by X-ray analysis (R. B. Tripp, oral commun., 1977).

Molybdenum

Molybdenum was detected in only one sample, yielding a value of 10 ppm. The sample was from an iron-stained zone along the Hope road, about midway between Sunrise and the junction of the Hope road with the Seward highway. Molybdenite was reported from the Alaska Oracle mine (51) (Tuck, 1933, p. 509; Smith, 1942, p. 186), and Tuck (p. 491) stated that it has been reported from several other localities. Martin, Johnson, and Grant (1915, p. 137) reported molybdenite in quartz veins near the head of the Chickaloon River (T. 6-7 N., R. 4 W.), but no confirmed occurrences of molybdenite are known in the Seward and Blying Sound quadrangles. On Crow Creek, about 6 km north of Girdwood and in the Anchorage quadrangle, Martin, Johnson, and Grant (1915, p. 137) and Park (1933, p. 409) observed molybdenite in several vuggy quartz veins on the Agostino property.

Nickel

Nickel in anomalous amounts was detected only in serpentinized dunite (97, 101) of the Resurrection Peninsula, giving values of 2,000 to 5,000 ppm nickel. Background values of nickel in pillow basalts, sheeted dikes, gabbros, and mafic tuffs from throughout the Seward and Blying Sound quadrangles commonly ranged between 5 and 100 ppm. Nickel in trace amounts has been reported (Lincoln, 1909, p. 209) from the Beatson mine (256) and from the Duchess mine (258) (Stejer, 1956, p. 114). On Knight Island, "nickel-bearing lodes" were reported in the pyrrhotite ores of Mummy and Drier Bays (Johnson, 1919, p. 145; Martin, 1919, p. 22, 23, 31), but the nickel probably was a minor element.

Platinum group elements

Seven samples from the Resurrection Peninsula were analyzed for platinum group elements: platinum, palladium, rhodium, rubidium, iridium, and germanium. The samples were one basalt dike, five serpentinized dunite rocks, and one beach sand from near the dunite. The greatest values obtained from serpentinized dunite (97) were 0.005 ppm platinum, 0.01 ppm palladium, and 15 ppm germanium. The beach sand yielded 0.005 ppm palladium and 3 ppm germanium. No platinum group elements were detected in the basalt dikes.

Tellurium

No significant occurrence of tellurium is known in the Seward or Blying Sound quadrangles. Analyses of tellurium were made on 22 samples from the Nearhouse and Smith mine (12), and tellurium was present in all samples, yielding values that ranged from less than 0.02 ppm to 0.16 ppm (P. R. Mitchell, unpub. data, 1977). In the Port Wells district but in the Anchorage quadrangle, gold-bearing quartz veins of the Homestake mine contain nagyagite, a sulfotelluride of lead, antimony, and gold (Mines Handbook, 1927, p. 158). Thus undetected telluride minerals may exist in the Port Wells district of the Seward quadrangle.

Tin

Tin was detected in only one sample (171), a sheared sandstone from near King's Bay that contained 50 ppm.

Titanium

No important concentrations of titanium were found; titanium constituted 1 percent or less of rocks analyzed geochemically. Titanium minerals identified include ilmenite, titaniferous magnetite, leucoxene, and sphene, all of which are accessory minerals found chiefly in the mafic igneous rocks.

Vanadium

Vanadium in many of the mafic rocks commonly ranges between 100 and 250 ppm; it also occurs in many gold lodes but in smaller amounts than in the mafic rocks. Only one occurrence (95) is considered anomalous, 2,000 ppm vanadium, detected from an iron-stained zone of gabbro on the Resurrection Peninsula.

Zinc

Sphalerite (ZnS) is a fairly common accessory mineral in the gold lodes where it generally is associated with galena (PbS). Although sphalerite is a common accessory mineral in the copper lodes of Prince William Sound and Blying Sound, galena rarely was reported in association with it in this environment. Only trace amounts of lead were detected in the mafic rocks, except in shear zones. Sphalerite also occurs in sheared granite at Wells Bay (184).

NONMETALLIC COMMODITIES

Large resources of sand, gravel, and rock suitable for industrial and construction use are common in the Seward and Blying Sound quadrangles. These commodities are distant from any major urban area, and transportation costs limit their use mainly to road building and local construction projects. Other nonmetallic commodities are minor and uneconomic, except perhaps for local use of limestone (tufa) near Seward.

Asbestos

Asbestos was reported (Grant and Higgins, 1910b, p. 79) in irregular veins mixed with quartz in a prospect (262?) on the southeast side of Elrington Island. Some of the veins are 8 cm wide, with the asbestos fibers formed perpendicular to the vein walls. This is the only reported occurrence of asbestos in the Seward and Blying Sound quadrangles, and its existence was not verified in our study.

Barite

Barium was detected in amounts of 5,000 ppm or greater at locality 247 where it is disseminated in iron-stained greenstone near a shear zone. No barite was observed in the outcrop. Barite prospects are reported (U.S. Bureau of Mines, 1973b, and KARDEX, 1976b) along Puget Bay (176, 177, 178, 179), localities not visited by the writer.

Boron

Boron was detected in an appreciable amount in only two samples from localities 12 and 26. At both places values of 2,000 ppm were obtained from quartz veins that cut sandstone of the Valdez Group. Many samples were analyzed from locality 12, the Nearhouse and Smith mine; boron was detected in most of them but only one sample yielded a high value (P. R. Mitchell, unpub. data, 1977). A boron value of 700 ppm was obtained from iron-stained rock at the margin of granite in the Harding Icefield area, the locality described under "Bismuth." Tourmaline, a boron mineral, occurs locally in the granite.

Fluorite

Small quantities of fluorite, associated with pyrite, were reported by Mendenhall (1900, p. 306) in quartz veins cutting slate and sandstone on Passage Canal. This is the only known report of fluorite in the map area, and it seems likely the notation is in error as fluorite was not found in any of the other numerous sampled and explored quartz veins.

Haydite

Haydite (75), the commercial name for expandable argillaceous rock, crops out along the highway near Moose Pass. The rock is well-indurated, thin-bedded argillite and slate interfingering with lenticular beds of fine- to medium-grained hard massive sandstone (Plafker, *in* Eckhart and Plafker, 1959). Reserves could not be estimated adequately, but the geologic map of the deposit represents a stratigraphic interval of about 115 m, exposed along strike for 525 m and for a vertical distance of more than 30 m; similar rock may be present uphill from the roadcuts (Eckhart and Plafker, p. 63). Bloating characteristics are described in the same report.

Limestone

Limestone, not common in the map area, occurs chiefly in small, isolated pods or lenses within the turbidite sequences of the Orca and Valdez Groups. Two exceptions exist (61, 86), neither of which was visited by the writer. The limestone at locality 86 is tufa. A few tons of the tufa were burned for local use and reportedly made excellent lime. The source of the tufa is considered to be limestone pods of the Valdez Group, dissolved and reprecipitated by circulating ground water. Several springs in the general area are precipitating limestone, thus more tufa deposits may exist (Ralph Tuck, unpub. data, 1933).

Sand, gravel, and rock

Sand, gravel, and rock are widely distributed in the map area but are most abundant and readily accessible in the western part of the Seward quadrangle where they have been used chiefly as road metal and for other construction projects. Deposits of the unconsolidated materials are mainly glacial and fluvioglacial in origin and occupy extensive valley bottom areas in the Turnagain Arm, Kenai River, and Resurrection River drainage systems. Bedrock is abundant and is readily accessible for industrial use. Granite of Blying Sound and Prince William Sound probably could be used for building stone, but development and transportation costs would be excessive.

Sulfur

The pyrite deposits at Horseshoe Bay (258, 259), Latouche Island, investigated for their copper content in the early part of the century, were viewed as a possible source of sulfur in the 1950's. Pyrite is the principal sulfide mineral, constituting nearly 100 percent of the potential ore at several places. Other sulfide minerals are chalcopyrite, cubanite, sphalerite, pyrrhotite, arsenopyrite, and galena. The deposits, described earlier in this report, consist of a series of westward-dipping lenses of massive sulfides that range in width from a few centimeters to 18 m and in length from a few centimeters to 150 m (Stejer, 1956). The lenses are wider and longer at depth than they are at the surface, which led Stejer (p. 122) to suggest that the present land surface may be near the top of the bodies. The lenses may extend for a considerable depth below the present level of mine workings. No calculation of reserves was given by Stejer.

ENERGY RESOURCES

No significant indications of energy resources are known in the Seward or Blying Sound quadrangles. There are no known occurrences of coal or geothermal energy; nuclear fuels and petroleum are discussed briefly below.

Nuclear fuels

No significant occurrences of uranium or thorium minerals are known in the map area. Two prospects (27, 28) for radioactive minerals are known in the Seward quadrangle (U.S. Bureau of Mines, 1973a, and KARDEX, 1976a) but no details about either are published. In the Prince William Sound area, Wedow and others (1953) made reconnaissance investigations for radioactive minerals, sampling copper and gold lodes, granitic intrusive rocks, and adjacent contact metamorphosed slate and sandstone, but no significant radioactivity was found. The highest radioactivity, 30 ppm (0.003 percent) equivalent uranium, was obtained from granitic rock of Esther Island. In the Moose Pass and Hope areas, reconnaissance surveys of many gold lodes yielded values of no more than 20 ppm (0.002 percent) equivalent uranium (White and others, 1952). Eleven samples of gold-bearing quartz veins from the Nearhouse and Smith mine (12) near Hope were analyzed for uranium; one sample yielded 9.8 ppm equivalent uranium, and the other ten ranged between 0.2 and 2.5 ppm equivalent uranium (P. R. Mitchell, unpub. data, 1977). Sedimentary rocks of the Orca and Valdez Groups in the map area are considered unfavorable for uranium deposits because the sandstones are marine in origin, are tightly folded, and lack porosity (Eakins, 1975).

Petroleum

No petroleum resources are known in the map area, and the potential for them is low. Exposed sedimentary rocks are intensely deformed well-indurated turbidite sequences of the Cretaceous Valdez Group and the early Tertiary Orca Group. These rocks are tightly cemented, lack significant porosity, are metamorphosed to prehnite-pumpellyite and greenschist facies, and locally are intruded by granitic plutons. Offshore areas in Prince William Sound and immediately southeast of Montague Island are most likely composed of these same units, although they may be covered by a veneer of unconsolidated material (Plafker and others, 1975, p. 16). The area from Blying Sound to Montague Island probably has the same characteristics.

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